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THE OIL-FIELDS OF WESTERN CANADA.

By Campbell M. Hunter, O.B.E., M.A., A.M.I.C.E., F.R.G.S., F.G.S., F.Inst.Pet.

With world history now being made on the grand scale, you will not wish to be burdened with a detailed account of the history of the oil-fields of Western Canada. Still, a few dates are necessary, both as a background and to afford perspective to the remarkable growth of the Albertan oil industry in recent years.

Apart from reference to the tar sands of Athabasca in 1788, the striking of natural gas in 1885 at Langevin, 40 miles to the north-west of Medicine Hat, and the drilling of the Lineham well at Pincher Creek in 1902, the history of the present oil industry dates only from 1914, when the Dingman well was successfully completed on the north bank of Sheep Creek in Turney Valley, some 40 miles south of Calgary. The Great War of 1914–18 put a stop to further developments, fortunately, perhaps, because, in the light of future experience, drilling technique was not sufficiently advanced in those days to have resulted in the successful development of the field. It was not until 1924, when the Royalite Company brought in its historic No. 4 well, at a depth of 3740 feet, with a flow of 500 barrels a day of naphtha, that Turner Valley focused public attention. From first to last, this well yielded over 900,000 barrels of naphtha, valued at over $3,000,000—say, £650,000—which was a very good return (seven barrels go to the ton). From 1928, when the Home Oil Company well No. 1 came in at 700 barrels a day, until June 1936, despite several notable naphtha-yielding wells being completed, the tempo of development slowed down. In that month Turner Valley Royalties Company brought in the first crude-oil well at a depth of 6825 feet. Up to that date, with the exception of Model well No. 1, which has been a consistent producer of crude oil since 1931, practically the entire production of Turner Valley had been "vapour-phase oil"—*i.e.*, naphtha derived from "wet gas." Since 1936 the development of the field has been one of continuing success, thanks largely to the very wise conservation measures taken to protect the field.

Whilst the above developments were taking place in Turner Valley, other fields were being proven, details of which will be given later.

Areal and Geological.

The chief possibilities for development of oil-fields in Western Canada lie in the great plains and eastern foothills of the Rocky Mountains, constituting a great triangular area, 800 miles along the International Boundary, and extending 1600 miles northward to the Arctic Ocean. This area, approximating 650,000 square miles, is underlain by 1000–13,000 feet—say, 1 mile—of sediments, largely marine in origin. The structure is basin-like, with the Alberta syncline occupying the deepest part. The sedimentary section as a whole thickens gradually from east to west across the

plains and foothills, very great thickening occurring in the front ranges of the Rocky Mountains and farther west. The more important structural units within the southernmost part of this great belt are :—

1. The foothills belt.
2. The Alberta syncline.
3. The Sweetgrass arch.

Within this extensive, potentially petroliferous area, the geological column of formations, with their local names and approximate thicknesses in Turner Valley, is as follows :—

Tertiary		
Upper Cretaceous,	Edmonton sandstones	1500 feet.
,, ,,	Bearpaw Shales	100 ,,
,, ,,	Belly River sandstone	1500 ,,
,, ,,	Upper Benton shales	1600 ,,
,, ,,	Cardium sandstone	100 ,,
,, ,,	Lower Benton shales	750 ,,
Lower Cretaceous,	Blairmore sandstones	1150 ,,
,, ,,	Kootenay coal measures	150 ,,
Jurassic,	Fernie shales	175 ,,
Carboniferous, Devonian.	Mississippian—Madison limestone	1500 ,,

To the newcomer the stratigraphy of the foothills belt presents a veritable nightmare. Versed as he may be in the study of faults, he finds himself disbelieving the evidence of his own eyes, for the whole area is intensively strike-faulted, and is further complicated by deep-seated sole-faulting. The magnitude of displacement or throw of these faults is often staggering, not infrequently exceeding 5000 feet. Thus, one well in the centre of Turner Valley ran into a repetition of the surface formation at a depth of over 7000 feet. Again, what may appear to be a straightforward anticlinal fold often proves to be the surface expression of deep-seated overfolding. Turner Valley may be cited as an example, and until this was appreciated its eastern flank was starred by wells which ran into overfolded beds and the sole-fault which underlies the whole field.

The formations in the foothills, or disturbed belt, consist largely of hard shales, etc., with layers of abrasive sandstones, which rapidly wear out the rock-bits. Thus, it is by no means unusual for bits to have to be replaced every foot or so drilled, sometimes even more frequently. Furthermore, the strata dip very steeply, and faults, sometimes of considerable displacement, are common, necessitating the greatest care in drilling, if a straight hole is to be ensured.

On the plains, however, the strata encountered in the wells consist mainly of less indurated shales, and, as such, present little or no drilling problems.

Oil-fields.

By far the most important oil-field yet struck in Western Canada, or for that matter anywhere in Canada, is that of Turner Valley. In fact, Turner Valley can rightfully claim to be one of the most remarkable oil-fields in the world. Apart from having produced 8,902,734 barrels of naphtha—say, 1,100,000 tons—from 1924 to 1936, it has since produced

38,815,079 barrels—say, 5,600,000 tons—of high-grade crude oil of 44° A.P.I. from 190 wells the average depth of which exceeds 7500 feet. All these flow under their own gas pressure, none has as yet been abandoned, and their gas–oil ratio is less to-day than it was a year ago. Furthermore, the closure of the liquid-phase oil zone—that is to say, the depth below the base of the vapour-phase or gas zone to edge water—exceeds 4000 ft., a depth unparalleled in any other oil-field.

Prior to 1936 the field was regarded solely as a vapour-phase oil producer—*i.e.*, one in which naphtha was derived from passing the wet gas first through separators, then through absorption plants to extract another gallon or so of naphtha, and finally scrubbed to desulphurize it before being piped to Calgary and other towns for lighting, heating, and other industrial purposes. Even so, the excess production, amounting to hundreds of millions of cubic feet daily, was burnt in huge flares, only a small proportion being piped back into the exhausted Bow Island and Foremost gas-fields with the object of repressuring and replenishing them as a future reserve against the time when the Turner Valley field is exhausted.

As already mentioned, drilling in Turner Valley calls for the exercise of the greatest care, so as to ensure a straight hole. In the old days it was not unusual for a well to diverge over 30° from the vertical. Now drilling contracts specify a tolerance of not more than 3°, and the Government lay down that the well shall be completed within the central 10 acres of the 40-acre spacing per well.

The heaviest types of rotary rigs are used. According to D. P. Goodall and G. A. Connell, the common practice is to drill a 9- or 10-inch hole to between 600 and 1000 feet, ream all or part of this to 16¼ inches, and then run and cement 13⅜-inch casing with about 225 sacks of cement. A 9-inch hole is then drilled to about 10 feet below the top of the Madison (Palæozoic) limestone, to which depth 7-inch or 6⅝-inch casing is run and cemented with from 250 to 600 sacks of cement. A 6¼-inch hole is then drilled through the zones known as the upper and lower porous limestone, to approximately 10 feet below the top of the "dark or black lime," which is usually encountered about 450 feet below the top of the limestone. After drilling is completed, circulation is continued for about 45 minutes, to remove cuttings from the hole. Where mud is used for drilling fluid, the drill-pipe is then pulled to a point about 100 feet above the shoe of the production string, and the drilling fluid above this point is circulated out with water. The drill-pipe is then pulled, and a string of 2½-inch or 3-inch tubing is run to within a few feet of bottom, and the fluid displaced with oil, which, when high-pressure gas is not available from a near-by well, is swabbed down until the bottom-hole pressure is sufficient to lift the weight of the fluid column in the tubing. Setting a hook wall-packer in the shoe of the casing saves much time in swabbing.

Where high-pressure gas is available, oil and gas are introduced together into the tubing, and are circulated down the tubing and up the casing. As the gasified oil reaches the casing-head there is a noticeable vibration of the head, and the fluid from the well, which has previously been flowing into the suction pit, is turned into the separator. As soon as these first gasified returns are obtained, the oil-pump is slowed down, until finally,

when the density of the fluid column in the well decreases sufficiently and the high-pressure gas alone has sufficient energy to flow the well, the oil-pump is shut off. After a while it may be possible to pinch off the input gas and allow the well to flow unassisted. This method of bringing in wells practically eliminates the loss of oil which accompanies swabbing and stage-lifting methods.

All wells are given at least one treatment of hydrochloric acid following completion. The wells are all completed in the limestone, and, whilst quite a good flow used to be obtained from the limestone, it was found that treatment of the wells with hydrochloric acid increased the porosity of the formation and resulted in a very greatly increased yield being obtained. The general procedure is to give each porous zone a "wash" treatment to remove any drilling fluid remaining on the walls of the hole. The well is "kicked-off" following this treatment and, after testing for a short period, the well is killed and a formation packer is set in the middle hard zone between the upper and lower porous zones. After testing the penetration rate in each zone, the method of treating the well is decided. In some cases one treatment in each zone is sufficient, while in others several treatments may be necessary. The well is "kicked-off" after each acid treatment, using the same method as that employed following completion of drilling. After completion of all acid treatments, the well's flow is switched from the casing to the tubing. The amount of acid used varies considerably, several thousand gallons of 15 per cent. hydrochloric acid sometimes being found necessary for the best results.

Present drilling depths range from 7000 to over 9000 feet. The record for fastest drilling was made by Royalite 57, in which 7765 feet of hole were drilled in 103 days, including all shut-downs, being an average of 75·4 feet per day. While no comparison can be made between the two fields, it is interesting to note that on the Gulf Coast it is routine practice for 11,000–12,000 feet wells to be drilled in 30 days!

On completion the wells are carefully tested under varying flow conditions, so as to determine their bottom-hole pressure and most economical gas–oil ratios. Early this year a new method of determining production allowables was introduced on the advice of Dr. Grainger Brown. This is based on an allowable production of twenty-five barrels of reservoir fluid per acre, the minimum Government spacing being 40 acres per well, account being taken of the liquefied volume of the free and dissolved gas as well as that of the oil at the recorded bottom-hole presure. Wells with a gas–oil ratio of over 30,000 cubic feet of gas per barrel are classified as gas-wells. So long as the oil produced represents a fairly large part of the reservoir fluid, satisfactory results may be obtained by gauging the rate of reservoir fluid withdrawal by the rate of oil production. But in those cases where the gas produced by the well represents the larger part of the volume of the reservoir fluid withdrawn, satisfactory operation can be best obtained by limiting the rate of reservoir fluid withdrawal on the basis of the rate of gas production.

In most cases the gas represents about 60 per cent. of the reservoir fluid volume when the gas–oil ratio exceeds about 2000 cubic feet of gas per barrel of oil. The rate of withdrawal of reservoir fluid volume is therefore defined and controlled by the rate of gas production.

The net result of the application of Dr. Grainger Brown's method of regulating optimum economic production is reflected in the steady reduction of the gas–oil ratio, which in June 1942 was 3220 cubic feet per barrel of crude oil as compared with 4150 cubic feet in June 1941, whilst in the same periods the oil produced was 26,693 barrels and 25,786 barrels per day, respectively.

The crude oil is pumped to the refineries in Calgary, together with the naphtha still being produced from some of the older wells.

The following tabular statement shows the production of Alberta to the close of 1941, expressed in barrels.

Year.	Production.	Year.	Production.	Year.	Production.
1914–21	56,599 bbl.	1928	489,531 bbl.	1935	1,263,750 bbl.
1922	15,853 ,,	1929	999,152 ,,	1936	1,320,442 ,,
1923	10,003 ,,	1930	1,433,844 ,,	1937	2,796,908 ,,
1924	14,049 ,,	1931	1,455,195 ,,	1938	6,742,039 ,,
1925	168,643 ,,	1932	917,622 ,,	1939	7,594,411 ,,
1926	219,598 ,,	1933	1,013,040 ,,	1940	8,495,207 ,,
1927	332,133 ,,	1934	1,265,940 ,,	1941	9,908,643 ,,

Total: 46,512,602 barrels, or 6,500,000 tons.

While the above is the production for the whole of Alberta, it may be taken as an index of the production of Turner Valley, since the latter is responsible for about 99 per cent. of the totals.

The number of crude-oil wells drilled in Turner Valley since June 1936, as distinguished from the vapour-phase oil wells drilled prior to that date, has been as follows:—

1936	2 wells.
1937	22 ,,
1938	36 ,,
1939	34 ,,
1940	35 ,,
1941	46 ,,
Total	176 wells to the end of 1941.

While the first crude-oil well in 1936 was drilled on the west flank of the south portion of Turner Valley, and was followed by intensive drilling in that area, the outstanding development of the field in the past three years has been its northern extension. Here a succession of wells has been drilled since Home-Millarville No. 2 was completed in January 1939, and yielded 220,000 barrels in its first year. The whole field is now over 17 miles long, with an average width of 1 mile. Of the 190 wells producing in July 1942, thirteen are enjoying an allowable production of over 400 barrels a day, and many have produced over 500,000 barrels apiece. Some of the wells are allowed up to 800 barrels a day. The "allowable" production per well depends on the gas–oil ratio and the bottom-hole pressure and whether the well is truly drilled in the middle of the 40 acres. One of the objects of this conservation is that the market for oil in Western Canada is limited, and the oil cannot be sent to Eastern Canada, where the market is enormous. There is thus only a limited economic area within which these wells can compete with American production, the

present rate of 27,000 barrels a day being practically the marketable limit.

Very high pressures are encountered in the wells in Turner Valley, several of which have come in with productions exceeding 2000 barrels per 24 hours. Recently, Foothills No. 9, in the north extension of the field, after an application of 4000 gallons of acid, responded with a flush flow of more than 3000 barrels a day, and a very low gas–oil ratio.

It is generally held that water-drive is not responsible for the large productions of the wells—in fact, the rate of edge-water encroachment has been scarcely noticeable, and in no way comparable with the recession of the fluid in the liquid-phase zone of the field. This circumstance lends emphasis to the imperative need for gas conservation in the vapour-phase zone or gas cap of the structure.

Such in brief is the history of the Turner Valley field up to date.

Outside Turner Valley, which is the sole field producing in the foothills zone, oil has been struck and is being developed in the following areas :—

	1941.		First half 1942.	
	Production.	No. of Wells.	Production.	No. of Wells.
Vermilion . . .	22,051	7	26,731	14
Wainwright . . .	11,733	6	6,981	6
Red Coulee . . .	11,626	7	5,194	7
Taber	5,600	1	5,151	2
Princess	19,587	2	4,132	1
Tilley	Nil	—	3,285	1
Dina	2,894	2	2,880	—
Del Bonita . . .	4,393	2	1,016	—
Lloydminster . . .	416	1	572	—

There are, in addition to the above, many areas where test drilling has been or is taking place, several of which will, it is hoped, justify the expectations of their sponsors. As it costs about £50,000 to drill a well in the foothills zone, it takes much courage to go into a virgin area and start drilling. The fields in the plains have been neglected through no glamour attaching to them. Turner Valley, with its very sensational results, has always been in the limelight, and it has been comparatively easy to finance Turner Valley propositions.

Vermilion.

Oil is found in the Lower Cretaceous formation at depths of from 1600 to 1900 feet, some wells having been drilled in 36 hours and costing as little as $12,000. The oil produced is of 14° A.P.I. gravity with a sulphur content of 3 per cent., and as such it is only suitable as liquid fuel.

While many wells have flowed at the outset, pumping has invariably to be resorted to. The field was discovered in 1939, and constitutes one pool in the Vermilion–Wainwright–Dina–Lloydminster area, being about 100 miles east of Edmonton.

Wainwright.

Although discovered in 1923, it has not been intensively developed, owing to difficulty in shutting off the water which is found in close proximity

to the oil-sand. The oil is struck at about 2200 feet in the Lower Cretaceous formation. The oil is black, contains a little wax, and is topped locally for engine distillate, fuel oil, and roofing asphalt.

Red Coulee.

This pool lies partly in Canadian and partly in American territory, and was discovered in 1930. Production comes from a sand in the Blairmore formation of Lower Cretaceous age encountered at a depth of about 2500 feet. The oil is of 30° A.P.I. and is locally refined. The field is spotty, due no doubt to variable permeability of the sand and the terrace-like character of the structure.

Taber.

This field is now very much in the limelight, since the productions obtained exceed those in other fields on the plains. The writer was responsible for the discovery of the field in 1931, when oil was struck at 3150 feet in the Cole–Hunter well. For years after, the prospects of the field were overlooked, and it is only in the last year that attention has again been focused on it. Some very good results have been obtained within the last few months.

Oil is encountered in the "Cut Bank" sand immediately overlying the Ellis (Fernie) shale. The "Cut Bank" sand is, in the opinion of Mr. Irvine, the same as the "Dalhousie" sand which has been a consistent crude-oil producer in Turner Valley, even though in most wells it was shut off in the early quest for the more productive Madison lime. The completion, in July of this year, of the Standard of British Colombia's Well No. 1, with a yield of 3400 barrels in the first nine days, was the signal for a miniature boom in oil leases at Taber. It is, however, too early yet to attempt to assess the value of the field, although the sub-surface structure, as determined by geophysical survey, is encouraging.

Of the other fields in the plains little can as yet be said, since their productions are small, while the quality of the oil is not high.

Refining.

The principal refineries are in Calgary, where the Imperial Oil Company, the British American Oil Company, and the McColl–Frontinac Oil Company have thoroughly up-to-date refineries with a joint capacity of over 20,000 barrels a day. That is a very conservative estimate. The figure may be about 40,000 barrels a day. It is hoped to soon produce large quantities of 100-octane petrol, while in Turner Valley *iso*butane will be obtained from the natural gas, and an alkylate plant at the Imperial Refinery in Calgary will extract butylenes from the refinery gas.

Economic Aspects.

Despite the high cost of the wells in Turner Valley (£40,000–£50,000), the industry is flourishing. The cost of production is trifling, since all the wells flow, and thanks to the stringent conservation measures taken in recent years, the decline in production of the wells is very gradual. A long life to the field is therefore expected.

Owing to the high quality of the oil it realizes a good price—namely,

$1.35 per barrel for 33–33·9° A.P.I., increasing 2 cents per degree up to $1.97 for 64° or greater. As the crude averages about 44°, the field price is around $1.55 per barrel. Naphtha from the absorption plants on the field commands $2.28–2.44 per barrel.

Owing to the distance of the oil-fields in Alberta from the important markets in Eastern Canada, the industry is placed at a disadvantage, which can and will only be overcome when the production warrants the construction of a pipe-line to the Great Lakes. It is worth noting that the distance between Hudson's Bay, which is 1100 miles from Calgary, and Liverpool is considerably less than the distance between this country and Trinidad, the West Indies, or Rumania. In the opinion of those conversant with the geological prospects of the foothills zone, it is only a question of time for the construction of such an outlet being consummated. It is largely with this thought in mind that several of the largest companies have clubbed together to drill a deep well in Turner Valley to test the Devonian underlying the Madison lime. Farther west in the foothills, at Moose Mountain, the Devonian is petroliferous, and again in Fort Norman area it is furnishing a valuable supply of oil. Fort Norman is in the Arctic Circle. Hopes are therefore running high as to the outcome of this deep test, which will exceed 10,000 feet in depth.

Athabasca Tar-Sands.

Without question the most remarkable manifestation of oil in the world is that afforded by the tar-sands of Athabasca in the neighbourhood of McMurray. The areal extent of these is estimated at 10,000 square miles, but owing to the thickness of overburden being in the light of present technique, excessive, only some 20 square miles are considered workable under current operational conditions. Even so, this area is estimated to yield 500,000,000 barrels of oil, or about 70,000,000 tons of oil, as compared with one hundred thousand million barrels in the whole area. The world's consumption of oil for about 25 or 30 years could be supplied by this one enormous area.

An interesting feature about the tar, which is extracted by the simple process of boiling the sand, is that it is extremely susceptible to heat, and, as a result of mild digestion, its gravity is raised from 10° to 20–22° A.P.I., which makes it easy to handle. It has been suggested that the Athabasca tar-sands may be regarded as an intermediary ancestor of crude petroleum, and that, had heat and pressure conditions been present, the tar would have been converted into what we term crude petroleum. In other words, the tar represents a transitional link between the raw material and crude oil. It is, however, only in the last two years that the tar-sands have been worked on a commercial scale, and those qualified to speak about the results are confident that the crude can be cracked catalytically for the manufacture of 100-octane petrol and that buna-S synthetic rubber can be produced by cracking and alkylation.

The recent completion of the Edmonton Alaska highway opens up great prospects not only for the Athabasca tar-sands, but also for the further development of the oil-field near Fort Norman. Here a number of wells have been drilled into the Fort Creek shales in the Upper Devonian, and are producing several hundred barrels of excellent oil, which is refined

locally, and finds a ready market among the many mining companies and river transport vessels.

Conclusion.

The subject of this paper is, like its areal extent, so vast that no matter how it is approached it cannot be adequately dealt with in the prescribed time. One thing stands out from the mass of information already available on the subject—namely, that the oil-fields of Western Canada, in conjunction with the tar-sands of Athabasca, are destined to play an increasingly important part in the economic development of the Dominion of Canada, and the sooner this is realized the more self-evident will it become.

Bibliography.

Apart from many informative articles in the Canadian and American technical Press, the subject of this paper has been very fully covered by bulletins issued by the Geological Survey Department of the Dominion of Canada ever since oil was first struck in 1914. Since 1924 Dominion geologists, under the able leadership of Dr. G. S. Hume, have carried out many surveys and published geological maps of the foothills and plains. These have been supplemented by excellent detailed statistical reviews by Mr. J. L. Irwin of the Department of Lands and Mines of the Province of Alberta, to whom the author is indebted for many of the photographs which illustrate this paper.

Among the many notable publications may be cited :—

(1) "Development of the Athabasca Tar Sands," by Max. W. Ball (*Canadian Inst. of Mining and Metallurgy*, Vol. XLIV, 1941).
(2) "Origin of McMurray Oil Sands," by J. C. Sproule (*American Association of Petroleum Geologists*, Vol. 22, No. 9).
(3) "Possible Future Oil Provinces in Western Canada" (*American Association of Petroleum Geologists*, Vol. 25, No. 8).
(4) "History of Alberta Oil," by F. K. Beach and J. L. Irwin.
(5) "Drilling and Completion of Oil and Gas Wells in Alberta," by D. P. Goodall and G. A. Connell (*Canadian Institute of Mining and Metallurgy*, Vol. XLV, 1942).

THE INSTITUTE OF PETROLEUM.

A MEETING of the Institute of Petroleum was held at the Junior Institution of Engineers, 39 Victoria Street, S.W.1, on Thursday, December 17th, 1942, at 4 p.m. The President, Mr. C. Dalley, occupied the Chair.

The following paper was read :—

"The Oilfields of Western Canada." By Campbell M. Hunter, O.B.E., M.A., A.M.I.C.E., F.R.G.S., F.G.S., F.Inst.Pet. (see pp. 75–83).

DISCUSSION.

THE PRESIDENT, in opening the discussion, said he had been very interested in the author's remarks concerning the rock through which he had to drill. Reference was made in the paper, in order to provide a comparison, to the fact that on the Gulf Coast it was routine practice for wells of 11,000 to 12,000 feet to be drilled in 30 days, which was about 400 feet a day, whereas in the case of the Turner Valley, in the well where the drilling was fastest the average rate had been 75·4 feet per day. He did not think that statement was complete unless the number of rock-bits used was given. In his own principal experience of drilling through heavy rock the rate had been 5 feet per week, and in a well 7000 feet deep over £35,000 had been spent on rock-bits, and if the same conditions obtained in Turner Valley the £50,000 to which the author had referred would be almost spent on rock-bits alone.

The author referred to a well being killed but did not say how it was done, and he would like to know whether it was killed with heavy mud or what method was used.

MR. T. DEWHURST said that the members were indebted to the author for the latest of a series of papers which from time to time had kept up to date their knowledge of developments in Western Canada.

The enormous oil-belt of Western Canada constituted only the northern half of the Rocky Mountain oil-bearing region, and that in turn represented only that eastern remnant of the Cordilleran geosyncline which had escaped the effects of the Laramide revolution.

A very wide range of the geological column was represented in the region in question, and in general it might be stated that the pre-Laramide formations were almost entirely marine, and that the younger formations were largely of brackish or fresh-water origin. In conformity with that source of origin, it might be inferred that the oil was pre-Laramide in age. The main oil-bearing stages would seem to be the Upper Devonian, the Upper Mississippian, the basal Jurassic, and the basal and lower parts of the Cretaceous. In any case it was probable that the main oil-forming stages were closely related to the major unconformities, the most important of which seemed to occur at the base of the Devonian, between the Palæozoic and the Jurassic, and also at the base of the Cretaceous. The earth movements associated with those and possibly other unconformities doubtless ushered in conditions suitable for the formation of oil, while later on the unconformities themselves would facilitate the subsequent migration of the oil. The extensive overlaps which occurred might have given rise to stratigraphic traps suitable for the accumulation and retention of the oil.

The author had referred to the very serious difficulties in the way of prospecting for oil in Western Canada. In the foothills belt those difficulties were due to complications of structure, involving low-angle thrust faults. The test drilling which had been carried out within the foothills belt in Canada and also farther south, in Montana, had as yet failed to disclose the existence of another Turner Valley oilfield.

With regard to prospecting in the plains, the great difficulty of detecting the presence of extremely gentle and closed structures was increased by the presence of glacial overburden, and it was much to be hoped that those difficulties would in time be resolved by geophysical methods of exploration. In that connection it might be presumed that the Athabasca tar-sand deposit was what he might term the corpse of what might have been an enormous oilfield, and it would be interesting if the author would indicate

whether he regarded this unique deposit as being due to gentle doming of the strata or to a terrace on a great monocline or perhaps to the presence of a stratigraphic trap. In any case, the existence of the deposit suggested that other deposits of oil, more deeply buried but nevertheless less moribund, might still lie undetected within the eastern homoclinal belt.

In conclusion, he would like to express his own thanks as a geologist, and no doubt the thanks of other geologists, who could not be present, to the author for his paper, and he would also like to wish the author every success in his strenuous efforts to develop the oil resources of the great Dominion of Canada.

Mr. R. J. Ward asked the author whether the extension in the north-western area of Turner Valley was still being developed, and whether he could state the type of oil that was obtained there.

The author had mentioned that the site of each well was 40 acres, and that one condition for increased allowables was that the well should be near the centre of the 160-acre area allotted. It did not necessarily follow that that would be the best site for the well, and he wondered whether the Companies developing the field were tied to the centre of the 160 acres, particularly in view of the axis of this extension running north-west–south-east and drilling areas had been divided into squares running north and south.

Mr. S. H. Chapman said the author stated that the common practice in Turner Valley was to drill a 9-inch or 10-inch hole and then ream out to 16½ inches. He would like to ask whether this practice of drilling a comparatively small hole followed by 7½ or 6½ inches of reaming was adopted because it was found easier to keep the hole straight, and also cheaper than drilling, say, a 14-inch hole, leaving only 2 inches to be reamed.

With regard to the limestone, he would like to know what proportion or percentage of it contained oil, and what was the porosity and permeability of the oil-bearing limestone.

Mr. C. T. Longcroft said the author had mentioned, when showing his slides, that in the Turner Valley oilfield an overfold had been encountered in a well which was drilled down to 7000 feet, and that the well had had to be abandoned. Surely overfolding did not necessarily preclude the presence of oil beneath the formations which were first encountered and then met with again in the reverse order. If he remembered correctly, "we used to encounter similar conditions in the Boryslaw field of Poland, but this did not prevent our finding oil beneath the overfold." He would be very glad if the author, as a geologist, could clear up that point.

Mr. E. H. Cunningham-Craig, in a written contribution read by the Honorary Secretary, said he was glad that the Institute was in ordinary session again, with a geological paper being read by one who was almost worthy of the title of "old timer," for Mr. Campbell Hunter had spent much time and done much hard work in exploring the delectable Province of Alberta, and was yet ready to seek for new marvels.

He thought that the author and he would probably agree fairly well as to the different stages into which they would divide the geological exploration of the oil-bearing lands. Possibly the author would give more attention to actual drilling and engineering problems, shows and productions of oil, while he himself would confine his studies for the first year or two almost entirely to geological structure. He would therefore date the commencement of the systematic search for petroleum some years earlier than most people would.

He did not know when it was that Dr. Dowling first took the field in Alberta; it was not before 1908, but he must have had a start of at least four years over anyone following him. Why had Dr. Dowling been apparently forgotten, instead of his sound geological methods being keenly followed? He could say with confidence that if Dr. Dowling had been followed, at least half the wells drilled in Alberta without oil being found would not have been drilled at all, or, to put it more fairly to all parties, exploration with the drill would have been delayed for a few years, until the complexities of the geological situation had been more thoroughly and scientifically studied.

At the beginning of 1912 there were only the pioneer geological maps of Dr. Dowling's to rely upon, and those were on the scale of one mile to half an inch, which was far too

small a scale for the mapping of such intricate structures as those encountered in the foothills of Alberta. Consequently there were mistakes both in stratigraphy and in structure even in those maps, but with large-scale maps to work on Dr. Dowling would have made no mistake at all. The point was that Dr. Dowling provided the keys to nearly all the problems and points of difficulty in the foothill regions of Alberta. The strong but often somewhat concealed asymmetry, the thrust-planes, with their riders, the general stratigraphy, could all be found in map and section in Dr. Dowling's work.

Those who came after Dr. Dowling, working on the six-inch scale—twelve times larger than his—made many mistakes in the first two or three years, but, correcting their errors as they went along, they gradually proved the truth of the most startling facts as shown on Dr. Dowling's maps and sections, made such emendations as were necessary, and now had a clear and consistent story of hundreds of square miles of the foothill country between the Athabasca tar-sands and the U.S.A. frontier which any geologist could read with ease.

He was sure that every geologist who had studied the foothill country by the only certain method—*i.e.*, large-scale mapping—would readily admit his debt to Dr. Dowling, who was a great geologist and had not been equalled, far less surpassed, by any of the official geologists who had had to tackle in recent years the somewhat difficult country in question.

It was perhaps unfortunate that the two strikes of oil in the Dingman well had been made so early in its history, for, although the oil was very highly filtered and gave a great stimulus to practical development, a very senseless boom was caused. Much confusion in geological ideas was also caused. The people of Western Canada were keen, enterprising, and anxious for quick results.

On the other hand, large-scale geological mapping took a long time. The natural results followed. It was well that the war of 1914–18 soon slowed up the budding oil industry. It carried on in a small way still, producing filtered oil: every new well brought in causing new encouragement. But geological work went on all the time, with declines and recrudescences, and bit by bit the story of Alberta's oilfield was pieced together.

Many wells were drilled, and nearly all were failures; certainly Western Canada got a bad name, although numerous stout hearts never gave up hope. It became the fashion to drill through thrust-planes or to attempt to drill into beds below where even the driest gas could be found. The same mistakes were made again, and would be made once more. Nothing could stop it.

At last, in 1929, the last particle of evidence that was wanted came to light, and the secret of Turner Valley was a secret no more. It was disclosed to only a few. But the brave men who would take the risk of drilling, drilled, within six years, and proved with one well all the real Turner Valley, north and south, as far as it had been followed. They deserved the title of discoverers, for they had worked out logically why the oil must be there, why it could be nowhere else, and why it must be of the quality it was. It was quite a romantic story.

He agreed with the author that there were still many untested chances for oil production in Western Canada, but, on the other hand, a very great deal was now known about the geology of Western Canada.

Much land that looked promising a few years ago must now be rejected. One or two localities had still great chances. Everyone wished Western Canada well, but qualifications to warrant careful examination were likely to be raised much higher than formerly. There was still much need for large-scale mapping.

Mr. A. P. Catherall, referring to the question of well spacing, asked whether the figure of one well to 40 acres or sixteen wells to the square mile was based on any scientific fact with regard to drainage area or whether it was just an arbitrary Government regulation.

Mr. Campbell Hunter said it was an arbitrary Government regulation.

Mr. Catherall said that on the last page of the paper it was stated that some 20 square miles of the Athabasca tar-sands were considered workable. With sixteen wells to the square mile, there would be about 320 wells, and they were to yield 500,000,000 barrels of oil, which would be about 1,500,000 barrels per well. That seemed to be a rather high figure.

MR. CAMPBELL HUNTER replied that it was not a question of producing by wells; it was a tar-sand proposition, the average content being about 19 per cent. bitumen.

MR. A. E. CHAMBERS asked whether the Turner Valley had proved itself to be a commercially attractive proposition. It seemed to him that it was very much limited by its geographical situation, as had been pointed out, and it would be easy to get over-production with so many wells. Perhaps the author in his reply would touch on the broad commercial aspect of Turner Valley.

MR. CAMPBELL HUNTER, in replying to the discussion, said the question raised by Mr. Chambers was obviously a very important one. His difficulty in dealing with it concisely was due to the way in which the Turner Valley field had been financed. The cost per well was such that in most cases a well was regarded as a unit of finance and was financed in different ways. In the old days it was financed by the promoters selling stock. Nowadays, except in the case of the Standard Oil Company and the larger companies, it was usually financed on a royalty basis, a certain number of royalty units being sold. The value of the unit was determined according to the probability of oil being struck in the site in question. The company holding the acreage would sell 50 units, say, at 5000 dollars per unit, which would bring in 250,000 dollars, a sum estimated to be sufficient for drilling the well. The promoters would retain the other 50 units for themselves and the overriding royalty owners. Therefore the dividends paid by the different companies represented only a very small proportion of the financial return which Turner Valley was making to its sponsors. He could only say that the proof of the pudding was in the eating, and as forty to fifty wells were being drilled per annum he considered it was fair to conclude that drilling in Turner Valley was a commercial proposition.

In answer to Mr. Ward, he explained that the 40-acre lot, known as a legal subdivision, was taken as the unit for locating wells. It was not based on any geological grounds.

In reply to Mr. S. H. Chapman, he stated that the porosity of the limestone varied considerably, and for that reason the limestone was treated with hydrochloric acid to increase its porosity.

The consumption of rock-bits varied enormously. When drilling through hard shale one could drill 120 or 130 feet, or even more, per rock-bit, and he had known 200 feet being drilled without the rock-bit being changed. When hard sandstone was encountered, the rock-bit might have to be changed after only 6 inches had been drilled. The rock-bits cost about $100 (about £20) each, and, speaking from memory, he thought in Turner Valley about 200 rock-bits were used per well.

So far as the killing of wells was concerned, they were killed with oil and not with mud; otherwise the process of cleaning out would be delayed a great deal.

Mr. Cunningham-Craig's remarks were very interesting. He thought that Mr. Cunningham-Craig could also claim to be a real "old timer" himself, as he had met him in Canada in 1914. He could not say that they had always agreed, but one learned much more by disagreeing with a person than by agreeing with him. There were undoubtedly going to be many pleasurable surprises and many heart-breaking disappointments. The foothills belt must not be considered as represented only by Turner Valley. Finance had been attracted to visible results, and when one tried to finance a likely structure elsewhere, the first question asked was: "Is it near Turner Valley?" If the answer was "No," people were not disposed to help to finance the proposition.

THE PRESIDENT, in proposing a vote of thanks to Mr. Campbell Hunter for his excellent paper, which had provoked a very good discussion, said that he himself already envisaged a scheme whereby the surplus gas from the Turner Valley would be injected into the Athabasca tar-sand as a method of recovery in place of the laborious system of extraction from the sand.

The vote of thanks was accorded with acclamation, and the meeting then terminated.

In a written contribution MR. I. A. STIGARD said that there seemed to have been few developments in Canada during the last quarter of a century, although Mr. Campbell Hunter had not touched on the subject of potential oilfields in British Columbia.

He had visited the "High River" district, a few miles south of the Turner Valley,

which had had very favourable reports and where concessions had been taken up and borings projected. At first sight, the field looked like an anticlinal valley with escarpments on either side dipping about 30° and 35° in the Upper Cretaceous series (which are, of course, unconformable on the Lower oil-bearing series). This structure seemed to have formed the basis of the section, but an investigation in the gorge at the bottom of the valley soon disclosed beds of the Lower Cretaceous series, exposed in nearly vertical beds dipping 75–85° in either direction. There was, of course, a big unconformity in the Cretaceous above the petroliferous series, and there was no relation in the structures of the two series.

Turner Valley had sometimes been exemplified as a typical anticlinal valley, but was probably much more complicated. He had, many years ago, given the opinion that the strata of the foothills were, in general, too much disturbed to provide good results, but that when deeper drilling became possible good results would be obtainable in the region where the prairie merges into the foothills, where the Cretaceous lies at great depth.

He did not know whether Mr. Campbell Hunter had given any attention to the region of the upper part of the Peace River Basin, in the part where British Columbia extended over the watershed to the eastern side of the Rockies, as this region seemed to have a more favourable structure than any other in the foothills.

The Wainwright Field had given rise to high hopes in 1920, but seemed to have shown disappointing results.

The Athabasca Tar Sands, which extend for over 10,000 sq. miles in a nearly horizontal position, seemed so far to have been exploitable only by distillation, but more development might be done in this direction. When struck at depth, however, the bitumen was found to be in a viscous condition, and became less inspissated with increasing depth. The gas which was always associated with these sands at depth (*e.g.*, Pelican at 600 ft.) was, however, exploitable, and was present over an enormous area in almost unlimited quantities.

Mr. Campbell Hunter had not alluded to experiments carried out by a Calgary engineer for the distillation of oil in wells in the "Tar Sands." Concessions had been obtained and attempts had been made to form a syndicate to carry these experiments into practice, but he had heard no results although the plan seemed to be open to wide possibilities.

Fort Norman and the Mackenzie Basin were a different story, although a boring at Pelican passed through the "Tar Sands" into the Devonian where traces of oil were found.

In conclusion, he did not think it was purely fortuitous that the International Boundary should divide a country with the greatest production in the world from one which, while larger in area, had a relatively poor production. He considered that the reason for this was financial rather than geological, and that it had been brought about by a lack of capital and enterprise.

OIL—AN ADDITIONAL BASIC MATERIAL FOR THE BRITISH PLASTICS INDUSTRY.

Extract from an Address before the Institute of the Plastics Industry, London Section, on Wednesday, 13th January, 1943.

By Dr. G. Tugendhat, M.Sc.Econ.

(*Director of Manchester Oil Refinery, Ltd.*)

Introduction.

The big and ever-growing family tree of the synthetic plastics and resins has its roots in many fields. Coal and coal-tar derivatives such as phenols, formaldehyde, urea, and many of the acetylene derivatives, fermentation products such as alcohols, and organic materials such as casein and cellulose have also contributed to its growth.

In the beginning of the industry many of these materials were considered to be of little industrial use, and were even regarded as waste products. In course of time the industry has called other materials, such as asphalt and bitumen and the large range of products derived from naphthalenes, glycerine, and other chemical materials, to its aid to act as fillers, extenders, and plasticizers. Many products, such as cellulose acetate, which entered the plastics industry in a subsidiary capacity, have, in the course of time, become of prime importance to the industry.

The rapidly expanding demand for plastics has raised its original raw materials to the rank of essential products. Until the outbreak of war few people questioned that the traditional sources of supply would be sufficient to meet the demands of the industry. However, due to war developments, these sources of supply are proving, in many cases, insufficient, and the industry is looking round for new raw materials. Already phenols are synthetically produced from benzol, and new sources are being opened up for the production of benzene, styrene, acetone, alcohols, and other solvents—to name only a few. Many of these bodies are being produced from oil in the U.S.A. in rapidly increasing quantities. This is a natural development, as all plastic materials contain hydrocarbons and petroleum is one of the cheapest sources of hydrocarbons known to man.

Before the war the total production in Great Britain, U.S.A., and Germany was estimated at not exceeding 200,000 tons per annum, of which England and the U.S.A. accounted for about 135,000 tons. If the Plastics Age is to become a reality, much larger quantities of plastics will have to be produced, and in many cases at lower prices than prevail to-day.

The oil industry presents the plastics industry with an abundant supply of relatively cheap raw materials. Furthermore, it offers new materials, many of them making possible new chemical synthesis.

I have been asked by your Committee to discuss to-day the following questions:

(1) The economics of oil refining in Britain instead of close to the oil-fields.

(2) A comparison between refining in England and the present set-up in the U.S.A.—could Britain expect costs to be roughly equivalent to the American?

(3) Which of our raw materials could be obtained from oil for:

(*a*) The older plastics, for instance, phenol—is it possible to give any indications of how costs would compare with materials produced by present methods?

(*b*) The newer plastics which some of us regarded as being essentially oil derivations and therefore economically almost U.S.A. preserves.

In order to discuss the economics of oil refining in Great Britain as compared with oil refining close to the oil-fields, it is necessary first of all to give a picture of the English market. In 1938, the last year for which full figures are available, the total consumption of liquid and solid petroleum products in Great Britain amounted to just over 11 million tons. About 40 per cent. of the consumption consisted of petrol, nearly 33 per cent. of fuel and diesel oil, 6 per cent. of gas oil, 4 per cent. of lubricating oil, the remainder being made up of kerosene and other refined products. Allowing for the difficulties of reconciling trade and consumption statistics, I would say that refinery production based on imported crude oil contributed about 1·8 million tons, or just over 15 per cent. to the total.

The main source of supply of finished products consumed in this country was the American Continent, which accounted for nearly 70 per cent. of the total imports—nearly 35 per cent. coming from the Dutch West Indies, 20 per cent. from the U.S.A., 9 per cent. from the British West Indies, and the balance from the Central American States. The distances these imports had to travel were from 3000 to 5000 miles. By comparison, the U.S.A. consumed in 1938 almost sixteen times as large a quantity of petroleum products as the U.K. in practically the same proportions. In other words, the break-up of the crude for England and America was almost identical. The task of the refining industry here and in the States working on similar crudes would, therefore, be pretty well the same.

As I have said before, we are importing the bulk of our finished products over an average distance of 3000 to 5000 miles. What is the position in the U.S.A.? The State with the biggest crude-oil production is Texas, which is several times the size of Great Britain. The main centres of consumption lie in the Eastern States in a triangle between Philadelphia, Boston, and Chicago. There are oil-fields in this area too, but, in order to meet the demands, 50 to 60 million tons per annum, or over 130,000 to 160,000 tons of crude oil and petroleum products, have to be imported every day of the year from the Gulf seaports. I do not know what the proportions of crude oil to finished products were ten years ago—at the end of 1940 over 70 per cent. of the daily imports consisted of crude oil, distillates, and fuel and less than 30 per cent. of fully refined products, mainly in the form of simple distillates. The distance from the Gulf ports to the Eastern seaboard is between 1800 and 2000 miles. From the point of view of proximity to the oil-fields the refinery manager in New York or Philadelphia is therefore not very differently placed from the refinery manager in the Manchester or London area. There are over 500 refineries listed in the U.S.A. to-day, and the break-up of this figure into simple refineries or topping plants and complete refineries shows that 78 per cent. of the complete refineries are right in the centres of consumption,* the remainder being at the meeting-points of the great waterways and the sea. The Gulf Coast, the gathering point of the world's largest and most prolific oil-fields, shows the smallest number of

* U.S. Department of the Interior, Report of Investigation R.I. 3616, February, 1942, p. 34.

complete refineries compared with the big centres of consumption in the industrial triangle in the north-east. By "complete refinery" I understand a plant fully equipped to produce all the commercial oil fractions meeting the most up-to-date specifications and to utilize the gases by means of modern synthetic processes.

The building of refineries in the oil-fields continues, but apart from the special refining industry which is arising in connection with the utilization of natural-gas wells, the plants are mainly of a simple kind, not expensive to build, and designed to produce standard products from the particular crude oil which they are working. Complete refineries in the centres of consumption are specially constructed to process many different types of crude, and it would be a waste of elaborate machinery to make it dependent on one oil-field alone.*

A refinery is primarily an instrument for the separation of crude oil into its various commercial fractions. The proportion of these fractions and the chemical constitution of the crude oil vary with the different types of crude, and it is the claim of these modern, or what one may call complete refineries, that they break up any type of crude according to market requirements. There is only one limiting factor—due to technical considerations, it is not possible to work a refinery of this type economically below a certain capacity, which to-day may be put at about 500,000–750,000 tons annual throughput. There are refineries in the U.S.A. with an annual capacity of well over 2 million tons, and the biggest are located just outside New York. It is held by many that only a very small saving, if any, accrues from these mammoth refineries. Be this as it may, even a 2-million-ton refinery could be regarded as covering only 20 per cent. of Great Britain's pre-war market.

How would the British refinery manager's task as far as erection and running costs are concerned compare with that of his American colleague? *Prima facie* there should be no difference. The equipment of a refinery consists of boilers, pipe-stills, various types of vessels, a lot of storage tanks, and many pumps, pipe-lines, cables, and instruments. Calculated on the throughput, the steel and other material requirements are small. Taking it all in all, there should not be much difference between the erection costs of a refinery in Great Britain and in the U.S.A. Quotations which I saw before the war bear out this statement. There is the fact that American steel manufacturers and certain Continental concerns have concentrated for many years on the production of special refinery equipment. Not much has been done on these lines in this country, but given equal concentration of effort, competitive prices for construction material, etc., I fail to see why erection costs in this country should differ materially from those of the U.S.A., especially after the first experimental work has been carried out.

The running of a modern complete refinery comprises, broadly speaking, the working of the following processes: straight distillation, treating, blending and extraction, cracking, and synthetic processes. Distillation is the only technical process I know of where, apart from the cost of fuel, you

* Most of these modern complete refineries work in close co-operation with the main chemical firms of the U.S.A., such as du Pont, Monsanto, Allied Chemicals, Commercial Solvents, Carbide & Carbon, etc.

can as it were unscramble your eggs as often as you like—if you pump all the fractions coming out of the distillation unit into one tank you would have the crude oil as before. The crude distillates are, however, not fit to meet modern fuel and lubricating specifications; furthermore, as their proportions are dictated by nature, the quantities very rarely conform to market requirements. To balance their proportions is the primary object of the cracking plant. Its original purpose was to crack the heavy and medium fractions into gases, petrol, fuel oil, and/or coke, and thus to increase the output of petrol from any given crude.

A synthetic department was added in order to utilize the gases and to produce from them new materials, the best known of which are *iso*-octane and similar compounds with an octane rating of 100 or more. To-day, by means of a number of operations such as hydrogenation, dehydrogenation, alkylation, isomerization, cyclization, not forgetting polymerization and reforming, the proportion of gases to liquids and the quality and quantity of gases can be varied within very wide limits by changes of operation, charging stock, and by different cracking processes. By these means the range of new chemical bodies produced from oil is steadily increasing. I might add that until a few years ago these very cracking gases were considered waste which could at best be used for heating purposes.

In the treatment and blending department the products from the fractionation and synthetic departments receive their final polish and adjustment to modern specifications. By employing physical methods of solvent extraction, aromatic bodies are separated from paraffins and naphthenes, or paraffins from aromatics and naphthenes. The latter processes are to-day mainly employed in the production of high-grade lubricating oils, kerosenes, and diesel oils; the former are becoming of increasing importance in the preliminary treatment of the petrol fractions. Although the solvent methods have largely displaced the old methods of chemical refining with sulphuric acids, acid treatment still plays an important part. I should also mention the various filtering and purification processes such as sweetening, clay treatment, dewaxing, and wax production.

Fuel, electricity, cost of the catalysts, chemicals, the replacement of corroded and eroded material, and provision for depreciation form the biggest items on the expense sheet of a refinery, on which the cost of labour represents only a comparatively small proportion. Again I do not see why the cost of fuel, heat, power, and chemicals in this country should be appreciably higher than in the U.S.A. In other words, given equal efficiency of operation, there should not be much difference between the two countries.

In this connection there remains one point to be discussed. It is the question of refinery waste, which looms so large in all discussions on refinery location in the centres of crude-oil production versus the centres of consumption. According to the laws of nature, the sum total of what is put into the refinery must be equivalent to the sum total of the products which come out. Waste is, therefore, a word which requires closer definition. In practice all physical refinery accounts show a certain shortage, due to evaporation and unavoidable errors in bringing a number of products down to a common denominator, etc. However, this refinery

shortage is small—the physical balance sheet of all U.S.A. refineries gives for 1940 a figure of 7½ million barrels on a total refinery throughput of 1300 million barrels, or just over one-half of 1 per cent. It is obvious that such a small figure can hardly affect the considerations of refinery location. Indeed, what is loosely termed "refinery waste" does not in fact represent a physical shortage, but refinery products which are unsaleable. Anybody who has had anything to do with refinery management here or in the U.S.A. will confirm that the waste of yesterday has, to a very large extent, become the necessity of to-day. The cracking gases have not only become the main source of aviation-fuel blending stock, but also of an increasing number of primary, intermediate, and finished chemical bodies. Over 300 chemicals are produced from them, covering such important materials as acetone, various types of alcohols, aldehydes, esters, ketones, toluene, glycerine, and glycol, not to mention butadiene and styrene. The production of acetone from petroleum in the United States is said to be 100,000 tons per annum and to account for almost two-thirds of their total acetone production. According to various official announcements, the petroleum industry has undertaken to produce the ingredients—butadiene and styrene—for nearly 600,000 tons of the 700,000-ton synthetic rubber programme, a quantity representing only a fraction of the industry's theoretical capacity. The extracts from the various solvent processes, particularly of the heavy fractions, were largely unsaleable on account of their high content of aromatics and unsaturates. It is just the presence of these bodies which makes them interesting starting materials for chemical synthesis. Even the acid sludges which have so long defied the attacks of the chemist are beginning to yield, and interesting bodies are in course of preparation.

Whilst I hesitate to generalize, I would say that the weight of liquid and solid materials leaving a modern refinery to-day for which there is no market is less than 2 per cent. In any case it is, I believe, small enough not to affect the question of refinery location. I hope I have made it clear that the gases, far from being waste, are to-day not only required to adjust the output of a refinery to market requirements, but are also essential for the production of high-grade aviation fuel and an increasing number of chemicals.

I have not bothered about transport costs, because as long as England has no crude oil resources worth speaking of, oil products must be imported in the crude or refined form. There is one thing to be said here in favour of crude, and that is that its contamination does not matter; it may even be imported in the bottoms of merchant ships. On arrival in England the crude oil could be pumped from the tanker through pipe-lines to the refineries to be erected in our big cities at an average cost of about 3*s*. to 4*s*. per ton for 100 miles, allowing for interest and depreciation on the pipe-line. At approximately the same rates, the refinery pipe-lines could also convey the bulk of the finished liquid products from the refinery to the principal centres of consumption, whilst the gases could be either converted on the spot or, where possible, transported in liquefied form by road or rail-car.

As I said before, hard facts, not theory, support the statement that the best location for a complete refinery is in the centre of consumption.

Indeed, looking at the papers published by the U.S.A. Department of Mines on refineries inside and outside the U.S.A., I have not been able to find out what is termed a complete refinery in the modern sense of the word anywhere near the centres of crude-oil production, although one or two exist in the big Gulf ports, and there are some which may be termed semi-complete near some of the big oil-fields in the world.

I think the best way of answering your third question will be to give a physical balance sheet, as it were, of a modern refinery. To date there exists, as far as I know, no complete refinery in this country, the bulk of the existing plant being asphalt refineries. Let us therefore assume that this country has decided to import 50 per cent. of its requirements in the form of crude oil and to erect refineries with a total capacity of, say, 5 million tons per annum and a cracking capacity of, say, 3 million tons. The synthetic units of these refineries would be equipped with every modern device for hydrogenation, dehydrogenation, alkylation, aromatization, polymerization, and all necessary treatment plants for the production of aviation fuel, high-grade commercial spirit, high-grade lubricating oils, waxes, etc. The great flexibility of these plants would enable their managements to buy crude oil from the most convenient and cheapest source and to work it up into proportions and qualities required by the market.

It is, of course, impossible to forecast post-war market requirements in this country, but in view of the great, I may say almost miraculous flexibility of the modern plants, I can confidently predict that any conceivable post-war demands for individual products could easily be met by the industry, and would in no way affect what I have just said about the economics of refining in this country. Furthermore, these plants could and would concentrate on the production of highest grade fuel, lubricants, dopes, and chemicals for the synthetic organic chemical industry. The balance of required imports would consist of the cheaper standard commercial products which it will undoubtedly be possible to buy on advantageous terms from the refineries near the oil-wells. I can even visualize the importation of cheap petrol for such motor-cars as we shall be allowed to run after this war, and the cracking of home-produced motor spirit into gases for the production of butadiene, aviation fuel blending stock, and similar high-grade materials. I think it is unnecessary for me to stress the advantages for our balance of payment and our trade policy that may be gained from buying crude oil instead of finished products, particularly high-quality products or chemicals.

To return to our probable refinery balance sheet. As I have said before, I cannot predict post-war demands, and in view of the ever-increasing flexibility of the plant, anything I may say to-day about possible products may to-morrow be out of date. However, to give you an idea of the products to be expected from British refineries with a total annual throughput of 5 million tons and a cracking capacity of 3 million tons, I will now give you one of many possible production programmes. Crude oil, as most of you probably know, is a liquid which contains a blend of thousands of hydrocarbon compounds, from the simplest structure, such as methane and ethane, down to the solids and semi-solids, such as asphalt, bitumen, and the paraffins. The last two have been the friends of the plastics industry

almost from its inception. Chloro- and nitro-paraffins are newcomers, but are rapidly gaining an important position for themselves.

In addition to over 4 million tons of liquid and solid products, there would be between 240,000 and 500,000 tons of gases. Without dehydrogenation or aromatization the yields of unsaturates, mainly ethylene, propylene, and butylenes, would be between 120,000 and 200,000 tons. These yields would be considerably increased by dehydrogenation. By a new aromatization process which has been developed in this country, using naphtha or gas oil as starting material, it would be possible to produce from each 100,000 tons of feeding stock approximately 25,000 tons of unsaturated gases, ranging from ethylene to butylenes, 30,000 tons of low and medium boiling pure aromatic liquids, such as benzol, toluene, xylene, naphthalenes, etc., the remainder being methane and ethane and a small fraction of heavy tar and coke.

Looking at these materials from the point of view of the plastics industry, I may say that it would be possible to produce many tens of thousands of tons of thiokol, polyvinyl chloride, styrene, methacrylates, glycols, glyptal resins, benzol for phenols, etc., not forgetting butadiene, acetone, acetic-anhydride and a goodly number of various solvents, plasticizers, varnish bases, and drying agents. Who shall say which unknown hydrocarbon fraction of to-day will not be one of the reigning monarchs of the plastics world to-morrow?

As crude oil contains only traces of oxygen, no nitrogen, and only a very small proportion of sulphur, which can easily be removed on cracking or by chemical treatment, it is comparatively simple to produce pure products free from these adulterating compounds. As hydrocarbons are present in every fraction of crude oil from the gases to the solids, every part of petroleum offers the possibility of chemical synthesis, and may be regarded as a potential brick for the plastic chemist.

I hope I have made it clear that the oil industry is capable of supplying large quantities of most of the starting materials for the plastics industry, not only the olefins, but also the full range of aromatics which were hitherto the preserve of the coal-tar industry. I should mention that it is also possible to produce from refinery gases formaldehyde and ammonia. This is already being done in the United States.

I believe that the only question your Committee has put to me which I have not answered is the question: "At what cost is it possible to produce the raw materials for the plastics industry?" As they all come out of the same cask, the allocation of the cost of individual items is, as many of you well know, practically impossible.

As a refinery manager I shall sell my products for what the market will pay for them. In so far as they are used for heating purposes their value will be mainly determined by their B.T.U. value, handling, and transport costs. Before the war the U.S.A. refineries were selling cracking gases for heating purposes at fuel oil prices, *i.e.*, 80 cents per barrel or $5 per ton, or less than one-fifth of one cent per lb. *iso*-Octane was and is produced from these cracking gases. Ten years ago one American gallon was claimed to be worth $500, and I believe there was not one gallon in the whole world. To-day U.S.A. refineries are selling 100 octane fuel at 11 to 13 cents per gallon allowing for profit and amortization of the plants within three years.

On the basis of this calculation, *iso*-octane should be worth about 17 cents per gallon. Therefore there is no reason to assume that the cost of other materials produced from cracking gases will not, on large-scale production, come down to similar lower levels.

It is claimed in the scientific books which I have read on the subject of plastics that the chemist of to-day not only knows how to build from simple substances complex molecules from which to form plastics, but that he is also able to determine beforehand most of the properties of the resulting material. There is no doubt that the physical chemists and chemical physicists are, with their mathematical formulas, increasingly transforming the old and homely methods. The industry has embarked on the great and adventurous journey of creating products designed to meet specified needs with maximum effect and minimum waste. There is no sphere in human industry or life in which plastics do not tend to play an increasingly important part. Dissatisfied with the limitations set upon its products by the very nature of the existing starting materials, the plastics industry is aiming at pushing its boundaries farther and farther afield. It is anxious to compete in heat and cold, ductility, elasticity, tensile strength, modulus and hardness, colour, beauty, touch, and resistance to wear and tear, with everything with which nature has provided us.

In practice all this poetry boils down to this. If the industry is to achieve its ambition, it must provide its workers with, I would say, almost unlimited supplies of cheap raw materials from which to build by large-scale production, old and new molecules. The chemist's hands must not be shackled by restricting him to a certain range of raw materials—nothing, to my mind, is more conducive to the creation of a new industry than the feeling that it can wallow in raw materials. It is, I believe, an unchallenged fact that it is practically impossible to meet the requirements of this country in petrol and other liquid fuels from coal by the known methods of hydrogenation: this quite apart from the fact that 4 to 5 tons of coal are required to produce 1 ton of petrol, and the cost of conversion is £10 to £12 per ton against £1 to £2, which is the cost of producing petrol from crude oil. The elimination, or even a considerable reduction, of our importations of petroleum products is, therefore, simply not practical politics, if the industry of this country is to be maintained on an efficient level. Therefore, the development of a synthetic chemical industry based upon oil does not raise the problem of importing new raw materials, but simply requires the substitution of refined products by crude oil which may be bought anywhere in the world.

In the U.S.A. a number of products which can be produced from oil are still being produced from coal in increasing quantities, thus proving that coal can hold its own against oil. In fact, recent research has, as far as can be judged from the meagre information given these days, paid great attention to the isolation and production of special hydrocarbons, oxygen, and nitrogen bodies from coal or coal-tar which should be of special interest as building bricks for the synthetic chemical industry, plastics, drugs, and dyes production.

There are bricks in coal and there are bricks in oil; there are, for that matter, bricks in a good many other places which I should have liked to mention, but which, as they do not form part of this address, I have

reluctantly left out. In fact there are bricks everywhere, and only intensive research, experience, and the application of methods of large-scale chemical engineering can and will prove the advantages of one God-given raw material over another for this or that process. Of one thing, however, I am certain—as certain as I am of anything in this life—and that is that unless we apply our minds to everything that nature has given us, we must, and we undoubtedly shall, fall behind those who are not content to restrict their minds and their labours to the scraping out of narrow corners, but have set their ambitions on exploring the whole world.